Prediction of Ecological Effects of Sea Level Rise in North Carolina through Coupled Hydrodynamic, Digital Elevation, and Habitat Models

J. Feyen[1], C. Auer[2], K. Hess[1], E. Spargo[1], A. Wong[1], S. White[3], J. Sellars[3], and S. Gill[4]
1. NOAA/NOS/Office of Coast Survey, Coast Survey Development Laboratory
2. NOAA/NOS/Center for Sponsored Coastal Ocean Research, Coastal Ocean Program
3. NOAA/NOS/National Geodetic Survey, Remote Sensing Division
4. NOAA/NOS/Center for Operational Oceanographic Products and Services

Introduction

Sea Level Rise (SLR) is a significant coastal stressor that threatens coastal ocean ecosystems. Without a good understanding of its impacts, it is difficult for coastal managers to develop plans to mitigate the effects of SLR. Valuable habitats such as oyster reefs, marshes, coastal forests, and submerged aquatic vegetation (SAV) beds occupy limited vertical and horizontal positions in the coastal environment and may be modified significantly by SLR. These threats are particularly acute for North Carolina, which is characterized by a fragile barrier island system that protects a series of non-tidal sounds. Changes to the hydrodynamic conditions within the North Carolina ecosystem by SLR can have major impacts on ecological processes.

A Coastal Flooding Model (CFM) has been developed for coastal North Carolina by combining a finite element hydrodynamic model with a continuous elevation dataset. Topographic LIDAR data relative to the North American Vertical Datum of 1988 (NAVD 88) was combined with bathymetric sounding data relative to local tidal datums by transforming the tidal datums with the vertical datum transformation tool VDatum. A continuous bathymetric and topographic (bathy/topo) Digital Elevation Model (DEM) was constructed to provide a seamless land/water interface. The CFM can simulate tidal response, synoptic wind events, and hurricane storm surge propagation in combination with SLR. Accurate prediction of inundation patterns is accomplished by high localized resolution in the coastal zone, continuous bathy/topo data, and an accurate wetting/drying algorithm. The CFM has been validated against observational data before modification of initial and boundary water levels to represent eustatic SLR. Shoreline migration can be dynamically computed from the CFM simulation output as a function of SLR, and the CFM will be coupled to ecological submodels to characterize the impact of SLR.

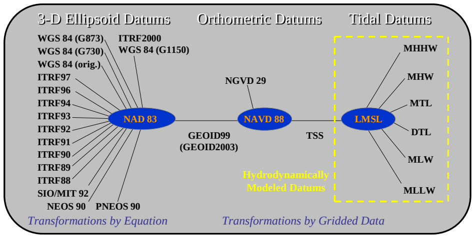

Figure 1. VDatum vertical datum transformation tool.

VDatum

In order for the CFM to accurately simulate inundation it requires a continuous bathy/topo elevation field. However, the vertical distance between local tidal datums and NAVD 88, for example, changes spatially according to variations in the shallow water hydrodynamic response and the gravitational field. Therefore, the VDatum vertical datum transformation tool has been developed by NOAA's National Ocean Service (NOS) for combining data from nearly 30 different tidal, orthometric, and ellipsoidal vertical datums (Milbert, 2002; Parker, 2002; Parker et al., 2003). VDatum is being developed on a regional basis for the U.S. coastline by NOS' Coast Survey Development Laboratory (CSDL), National Geodetic Survey (NGS), and Center for Operational Oceanographic Products and Services (CO-OPS). The tool uses observational and modeled data to transform between datums as shown in Figure 1. A version covering coastal North Carolina and the Albemarle-Pamlico sound system has been developed (Hess et al., 2004; Hess et al., in preparation) and is available at the VDatum web page: http://nauticalcharts.noaa.gov/csdl/vdatum.htm.

There are three main components of the North Carolina VDatum implementation. First, the Advanced Circulation (ADCIRC) computational model (Luettich et al., 1992) has been used to simulate tidal circulation over a one month period. The finite element mesh varies in resolution from tens of kilometers to tens of meters in order to resolve variations in tidal wavelengths and currents according to geographic features (Figure 2). Tidal datum fields have been calculated from the modeled water level time series and validated against CO-OPS observed tidal datums. Second, NGS benchmark data at CO-OPS tidal stations was used to determine the relationship between observed tidal datums and surveyed NAVD 88 benchmarks. NGS created a Topography of the Sea Surface (TSS) by spatially interpolating the data across the VDatum region to define the conversion between tidal datums and NAVD 88. Third, VDatum utilized a NGS geoid model that provides the relationship between orthometric and ellipsoidal datums. This model, based upon gravimetric data, describes the Earth's geoid across the continental U.S. and provides a link between NAVD 88 and GPS-relevant three dimensional ellipsoidal datums.

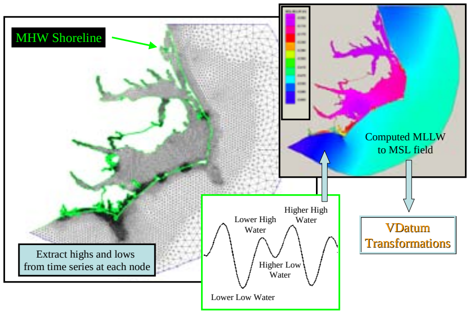

Figure 2. VDatum hydrodynamic tide model.

Digital Elevation Model

A high resolution digital elevation model (DEM) was constructed by NGS for the western Pamlico Sound portion of North Carolina (White and Sellars, 2004). The DEM utilizes Federal Emergency Management Agency (FEMA) LIDAR data for topographic information and NOAA hydrographic soundings for bathymetric information to produce a continuous bathy/topo DEM relative to NAVD 88. The DEM has 6 m horizontal resolution and vertical accuracy of 25 cm for land and 30 cm in less than 20 m of water. The final DEM covers the area shown in Figure 3, including Bogue, Back, Core, and western Pamlico sounds, the Neuse River, and the corresponding coastal shelf areas, barrier islands, and overland regions.

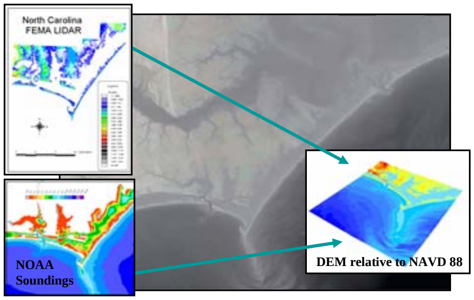

Figure 3. Continuous bathy/topo DEM with 6 m horizontal resolution.

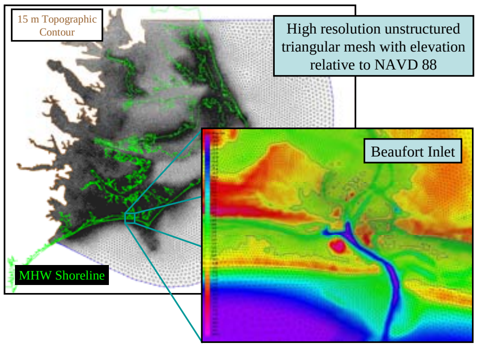

Figure 4. Coastal Flooding Model with detail of Beaufort Inlet, NC.

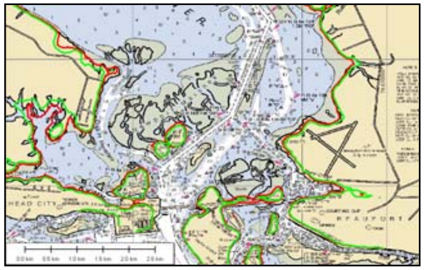

Figure 5. Computed present day (red) and 30 cm SLR (green) MHW shoreline for the lower Newport River, NC.

Coastal Flooding Model

CSDL has developed a predictive hydrodynamic model of North Carolina's coastal areas that combines VDatum products in an integrated modeling process. Using the DEM, land areas were integrated with the VDatum hydrodynamic tidal model to produce a Coastal Flooding Model (CFM). The purpose of the CFM is to study how SLR will affect the coastal ecosystem, and the CFM is unique because it treats the land and sea areas as a single, continuous environment relative to a uniform datum (i.e., NAVD 88). This model is able to simulate not only tidal response but also wind-driven (including hurricane) circulation to study changes in shoreline and inundation patterns with SLR. The mesh provides numerous computational points across inlets and waterways, and is aligned with shoreline and elevation contours. Resolution ranges from 5 km offshore down to 20 m within narrow channels (Figure 4).

The finite element model ADCIRC was used for the CFM because of its unstructured grid capability, computational efficiency, ability to model inundation, and validation as a storm surge model. It has an effective wetting and drying methodology that allows wave propagation and retreat over land. Tides were simulated with forcing specified by harmonic constants for 38 tidal constituents from a U.S. East Coast inverse model tidal database (Myers, unpublished, Myers and Baptista, 2001). Model output was harmonically analyzed at CO-OPS tidal constituent stations for the 23 constituents that can be extracted from a 32 day record. The RMS error at each station was calculated for the M_2, N_2, S_2, K_1, and O_1 constituents; the average of these RMS errors is 0.78 cm in amplitude and 6.57° in phase. Tidal datums were calculated by extracting highs and lows from the 32 day water level time series; the tidal range (Mean High Water (MHW) – Mean Low Water (MLW)) was compared to CO-OPS tidal datums; the average error is 7.09 cm. Modeled shorelines were computed by determining the intersection of tidal datum fields (e.g., MHW) with bathy/topo contours. Figure 5 shows the NOAA chart for the Newport River overlain by computed MHW shorelines for both current and a 30 cm sea level. Note this differs from the commonly used approach for determining SLR inundation of using a constant adjustment (e.g., the 1.0 m topographic contour) by accounting for the variations in water levels due to hydrodynamic effects.

Future Work

First, changes in tidal harmonic constants and datums (include shoreline) can be calculated under the effect of SLR. Second, synoptic wind events can be examined by forcing the CFM with wind fields and validating with water level records. This is important in the North Carolina sounds since much of the system is non-tidal and the primary inundation events are wind-driven. Third, the CFM can be utilized to study hurricane storm surge flooding of the NC system and changes in flooding with SLR. However, using the CFM to study changes in inundation with SLR is not complete without including ecological processes. Therefore, the CFM will be used to drive a suite of ecological submodels of processes including biological (e.g. marsh growth) and morphological (e.g., erosion, deposition) change. These submodels and the CFM will provide iterative updates to each other to generate an overall prediction of the ecological effects of SLR, including habitat change. This integrated modeling process will provide managers with modeling and mapping tools to assess the risk of SLR.

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